Response and adaptation of salmon of the Pacific Northwest and the Columbia River region – States of Washington and Oregon - to climate change

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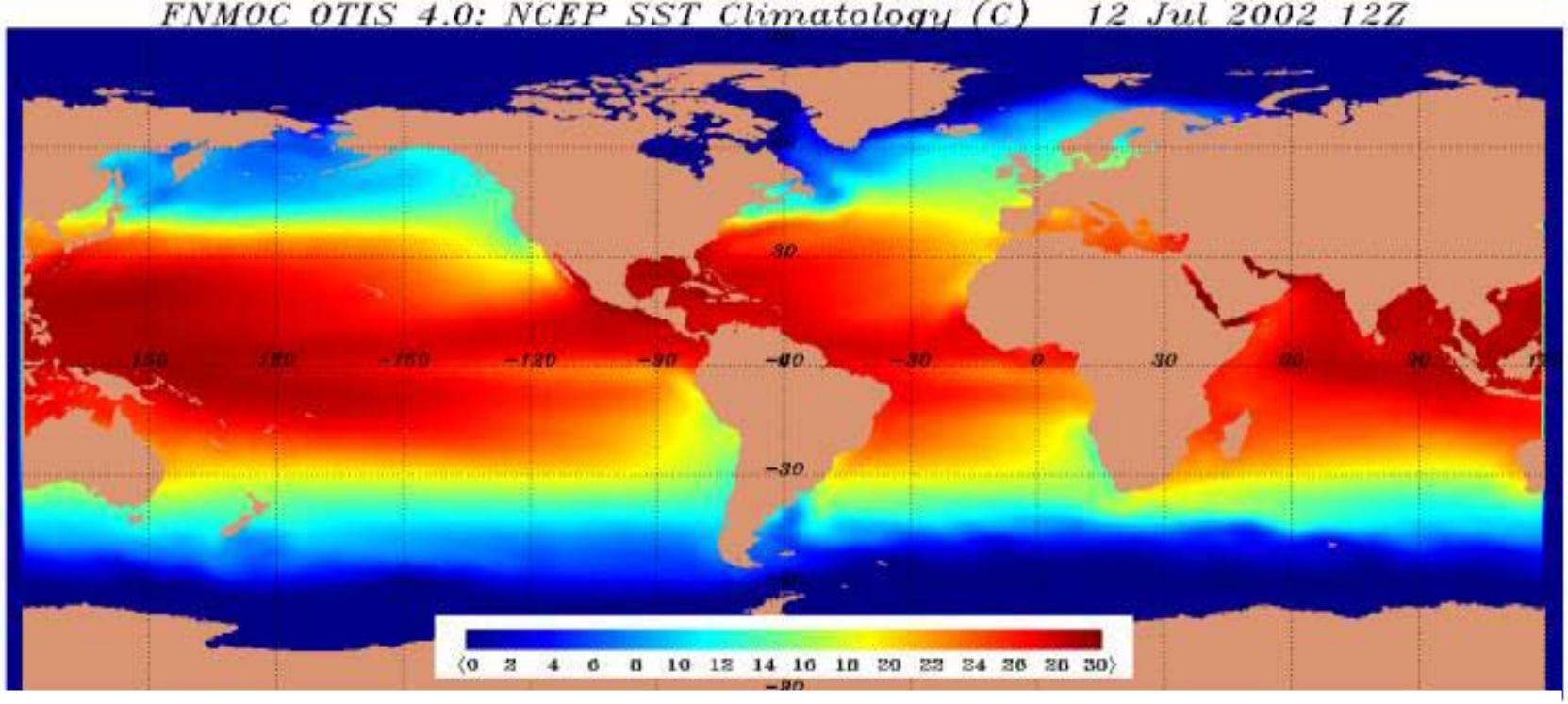


CHART OF SEA SURFACE TEMPERATURE

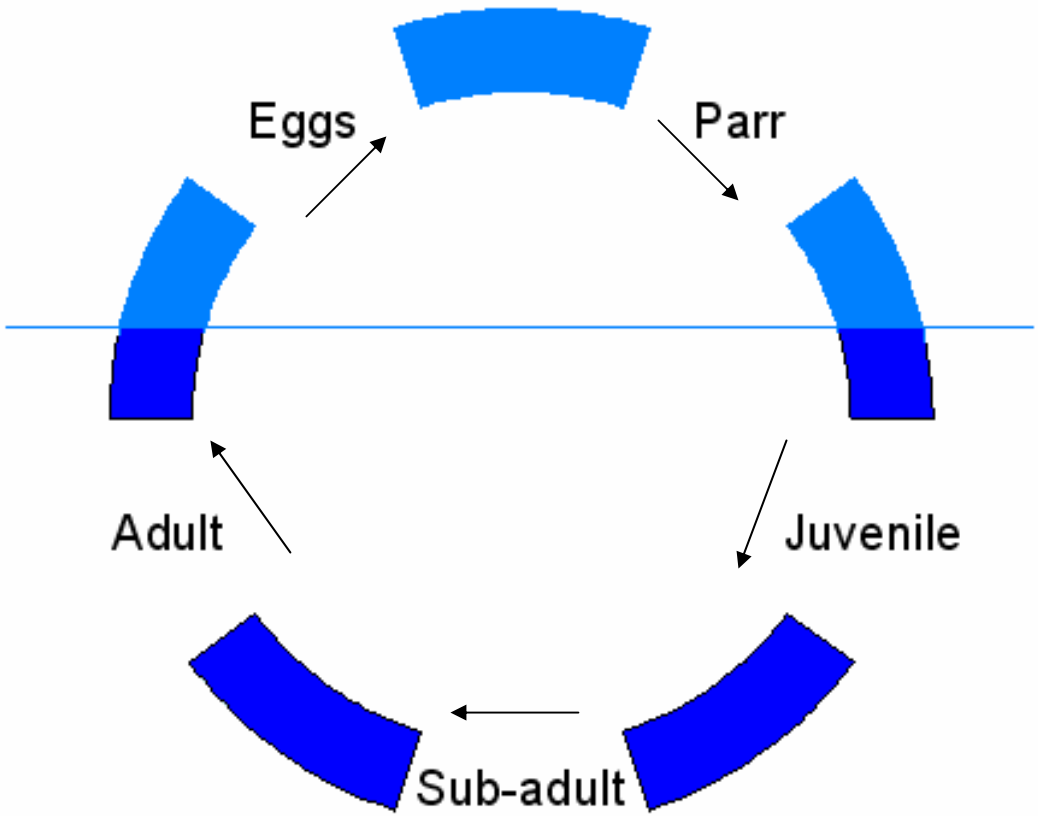
- Note: warm water between the equator and ~ 30 N
- Because of upwelling off North America, S. America N. Africa and S. Africa, cool water is found at the coast. Without upwelling, the coasts would be ~ 5-10☜C warmer during summer because offshore waters would move shoreward.
- Without upwelling we would have no salmon off PNW

To determine how Pacific salmon might respond to climate change, one needs to answer several basic questions

- When and where do they spawn in freshwater environments
- When do young salmon migrate to the sea
- Where they live in the ocean
- When to they return to spawn

Salmon put on 95% of the weight in the ocean and experience ~ 50% of their mortality in the ocean, therefore research on the ocean phase is important but surprisingly lacking – we have spent 10 years studying them in their ocean phase

Freshwater



Marine

Coho Salmon

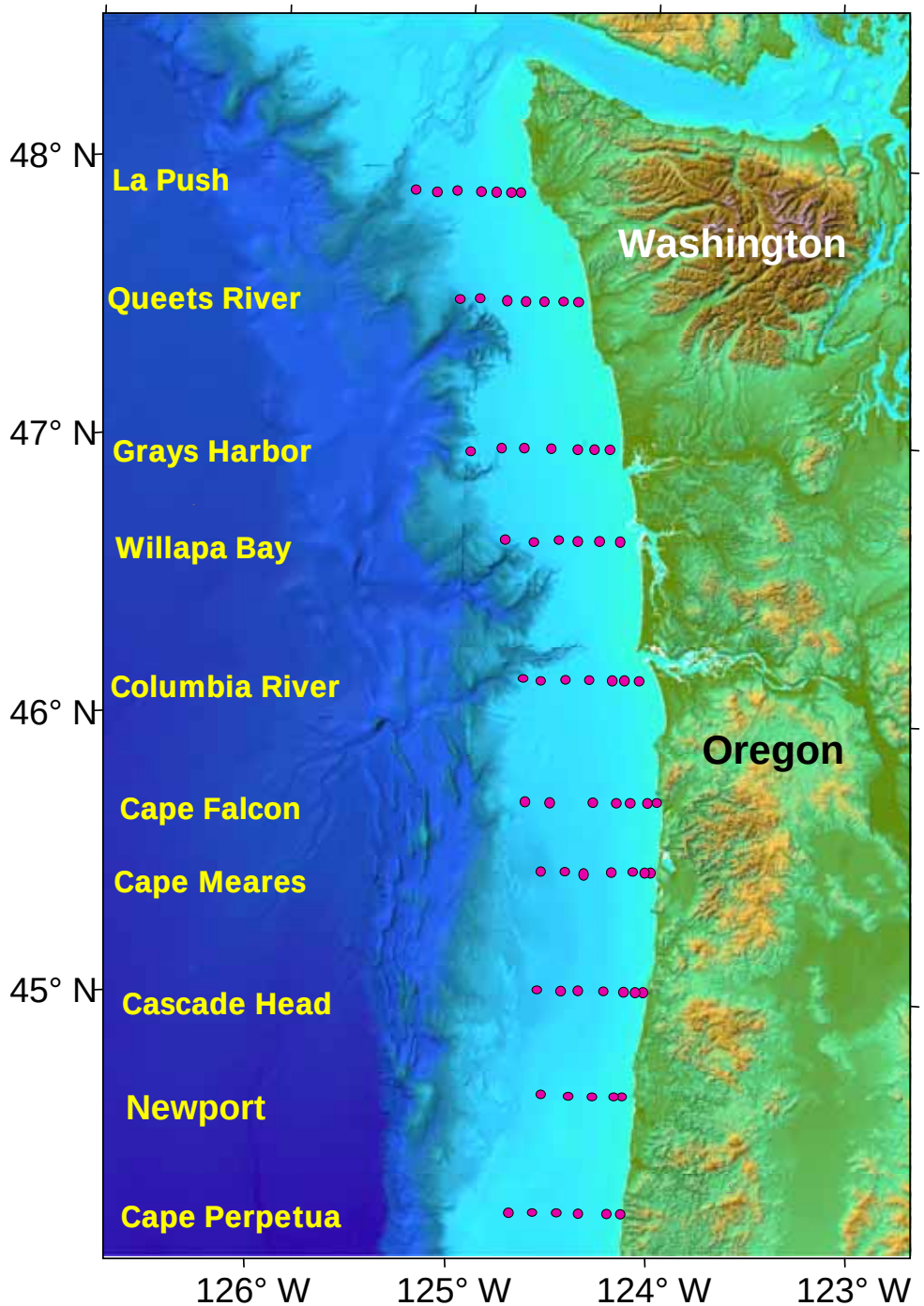
Eggs in November
1.5 year RIVER
Enter ocean in May
1.5 year OCEAN

Chinook (ocean type)

Eggs in November
0.5 year in RIVER
2.5 year in OCEAN
Enter estuary: May
Enter OCEAN Aug

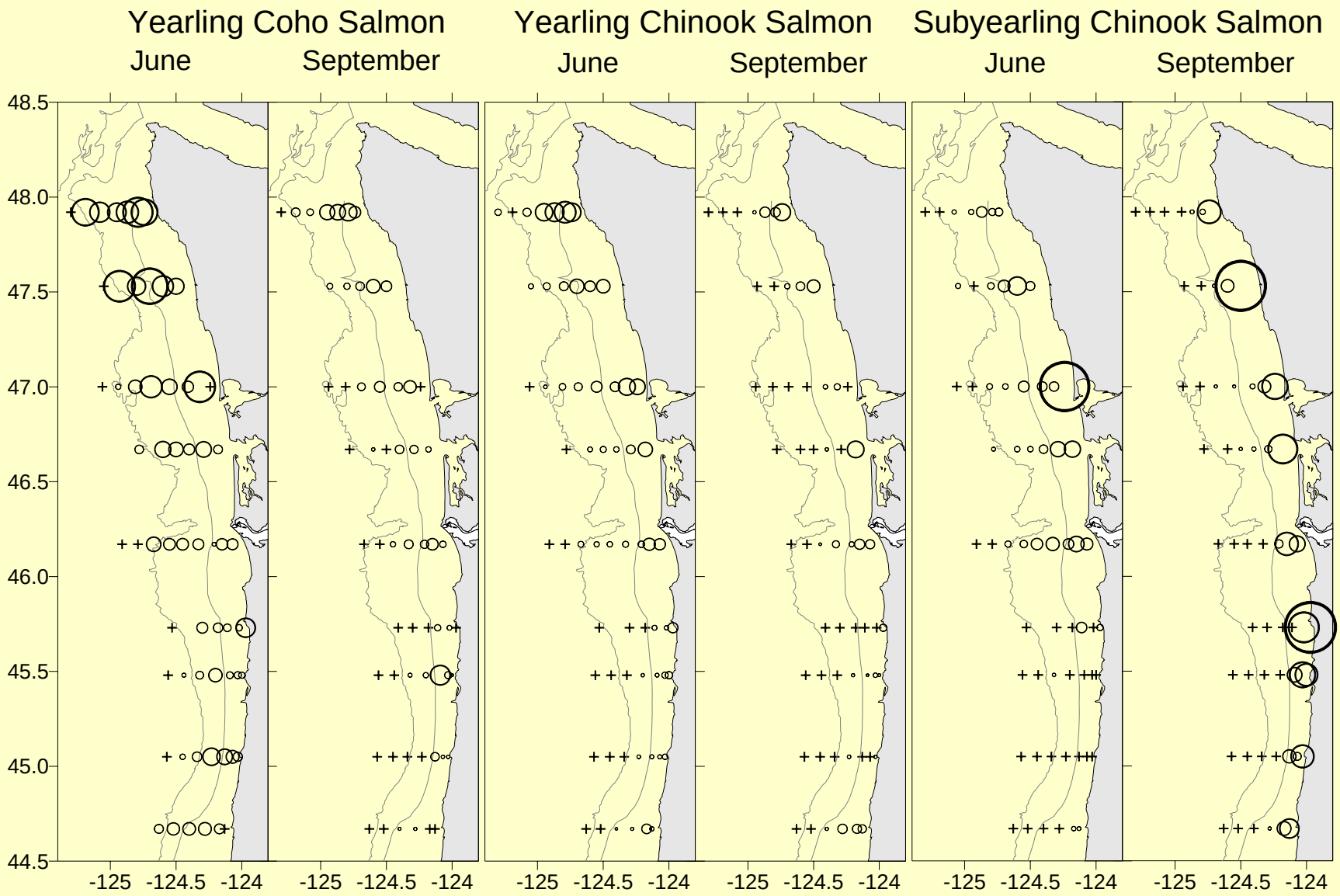
Chinook (stream type)

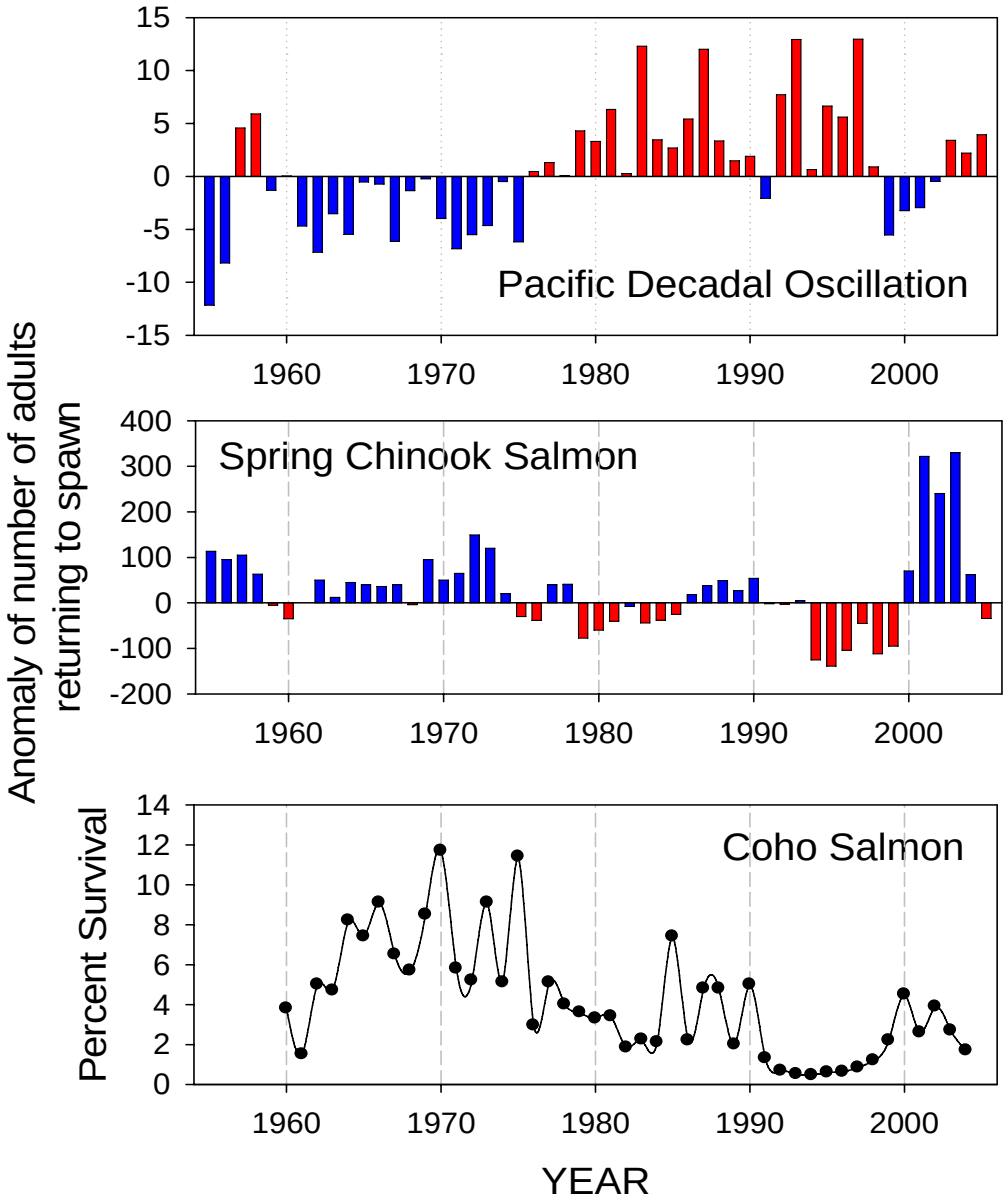
1.5 year in RIVER
≥ 2.5 year in OCEAN
Enter ocean in May



Salmon and Pelagic Fish Sampling

- Sample in May, June and September at ~ 50 stations since 1998
- Sample off Newport, biweekly, since 1996


Yearling Coho Salmon
June
September
Yearling Chinook Salmon
June
September
Subyearling Chinook Salmon
June
September
48.5
48.0
47.5
47.0
46.5
46.0
45.5
45.0
44.5
-125
-124.5
-124



PDO, coho and Chinook salmon

Coho and Chinook respond similarly

Table of qualitative indicators of ocean conditions:
Years with positive PDO can be disastrous
Years with negative PDO provide hope

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
PDO Winter (Dec-Mar)	9	3	4	6	2	10	6	8	7	1	1
PDO Summer (May-Sept)	7	1	2	3	4	9	8	10	6	5	
MEI (annual)	10	1	2	4	9	8	6	7	5	3	
MEI Jan-June	10	1	2	4	6	8	5	9	3	7	
SST at 46050	8	1	3	4	2	6	10	7	5	9	
SST at NH 05	7	2	1	3	5	6	10	9	4	8	
SST winter before	10	5	3	4	2	6	9	8	7	1	1
Upwelling April+May	5	1	9	3	4	8	7	10	5	2	
Mean Upwelling	7	6	2	3	4	1	9	10	5	8	
Physical Spring Transition	9	1	7	4	2	6	8	10	3	5	1
Deep Temperature	10	3	5	1	1	6	7	9	8	4	
Deep Salinity	10	2	2	4	7	8	9	6	5	1	
Copepod spp richness	10	2	1	4	3	7	6	9	8	5	
N.Copepod Anomaly	10	7	2	4	1	8	5	9	6	3	
X-axis Ordination Scores	10	4	2	3	1	6	7	9	8	5	
Biological Transition	10	4	1	4	3	8	6	9	7	2	1
Length of bio-upwelling season	10	2	4	2	1	7	8	9	6	5	
June-Chinook Catches	9	1	2	7	4	6	8	10	5	3	
Sept-Coho Catches	8	2	1	4	3	5	10	9	6	7	
Mean of Ranks	8.9	2.6	2.8	3.6	3.4	6.6	7.7	8.8	5.7	4.6	
RANK of the mean rank	10	1	2	4	3	7	8	9	6	5	
Coho Salmon Survival	0.012	0.023	0.044	0.025	0.037	0.025	0.019	0.020	0.018	0.009	
Number RED	15	1	1	0	1	8	10	15	3	3	

- We know that salmon are struggling in the northern California Current
  - Catch quotas greatly reduced in during summer 2007
  - Catch prohibited in summer 2008
- Why? Because upwelling has been extremely variable and freshwater habitats degraded
- Much attention by the media with articles in major U.S. newspapers: Seattle Times, Portland Oregonian, San Francisco Chronicle, Los Angeles Times, New York Times among others… and CNN this morning
- Now, salmon, much like ourselves, must face climate change

IPCC AR-4 report suggests…

- FRESHWATER ENVIRONMENTS: Precipitation will occur as rainfall, not snow

  → Rivers will be warmer with maximum flows in winter (rather than spring)

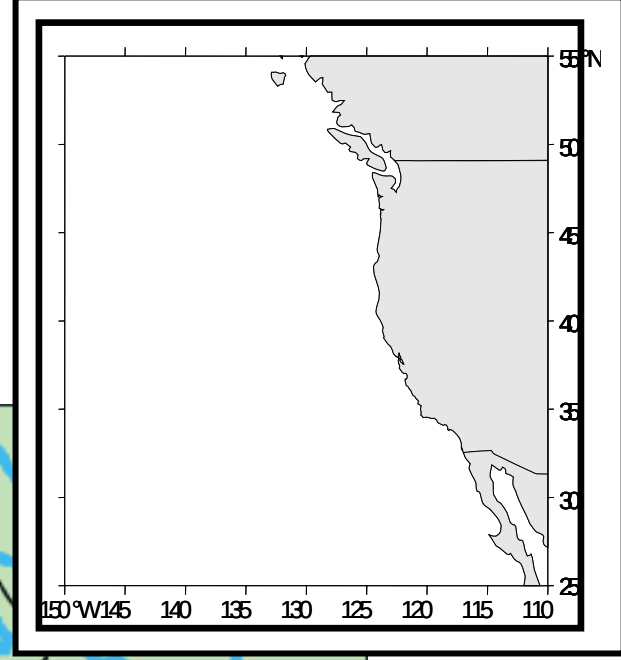
  → We suggest selection against spring run Chinook salmon

- MARINE ENVIRONMENTS: Changes in the ocean not well represented by the GCMs at the local scale, thus there is much uncertainty

- First principles and current research suggests that we should look at four factors: the PDO, coastal upwelling, the nature of the source waters that feed the California Current and impacts of these three physical factors on food chain structure

What about mitigation and adaptation…can we do anything for the struggling salmon…?

- Improve freshwater habitats damaged by logging; mitigate loss of habitats damaged by hydroelectric dams
- Restore “wild” salmon so as to increase genetic diversity
- Since we have been successful in forecasting, now the managers want help with timing of release of hatchery and barged fish



Boundary Dam
Chief Joseph Dam
Wells Dam
Grand Coulee Dam
Rocky Reach Dam
Rock Island Dam
Wanapum Dam
Priest Rapids Dam
Lower Monumental Dam
Lower Granite Dam
Dworshak Dam
Little Goose Dam
Ice Harbor Dam
Bonneville Dam
John Day Dam
McNary Dam
The Dalles Dam
Hells Canyon Dam
Oxbow Dam
Brownlee Dam

Acknowledgements

- U.S.GLOBEC Program
- Bonneville Power Administration
- NOAA/Stock Assessment Improvement Program
- NOAA/Fisheries and the Environment
- Biological Opinion

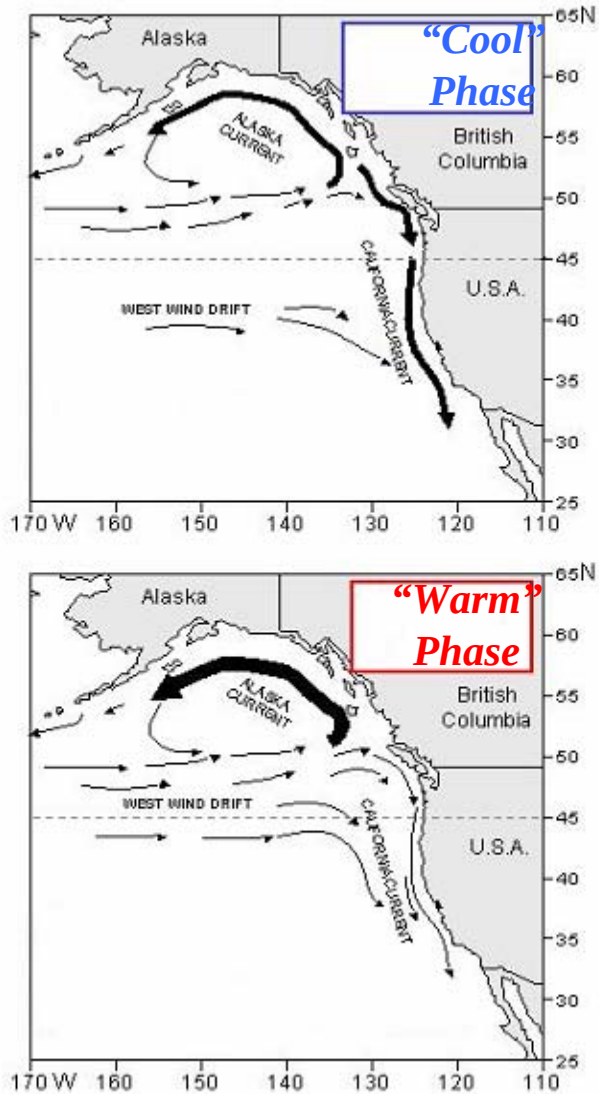
A working mechanistic hypothesis: source waters. . .

Cool Phase ➔

Transport of boreal coastal copepods into NCC from Gulf of Alaska

Warm Phase ➔

Transport of sub-tropical copepods into NCC from Transition Zone offshore



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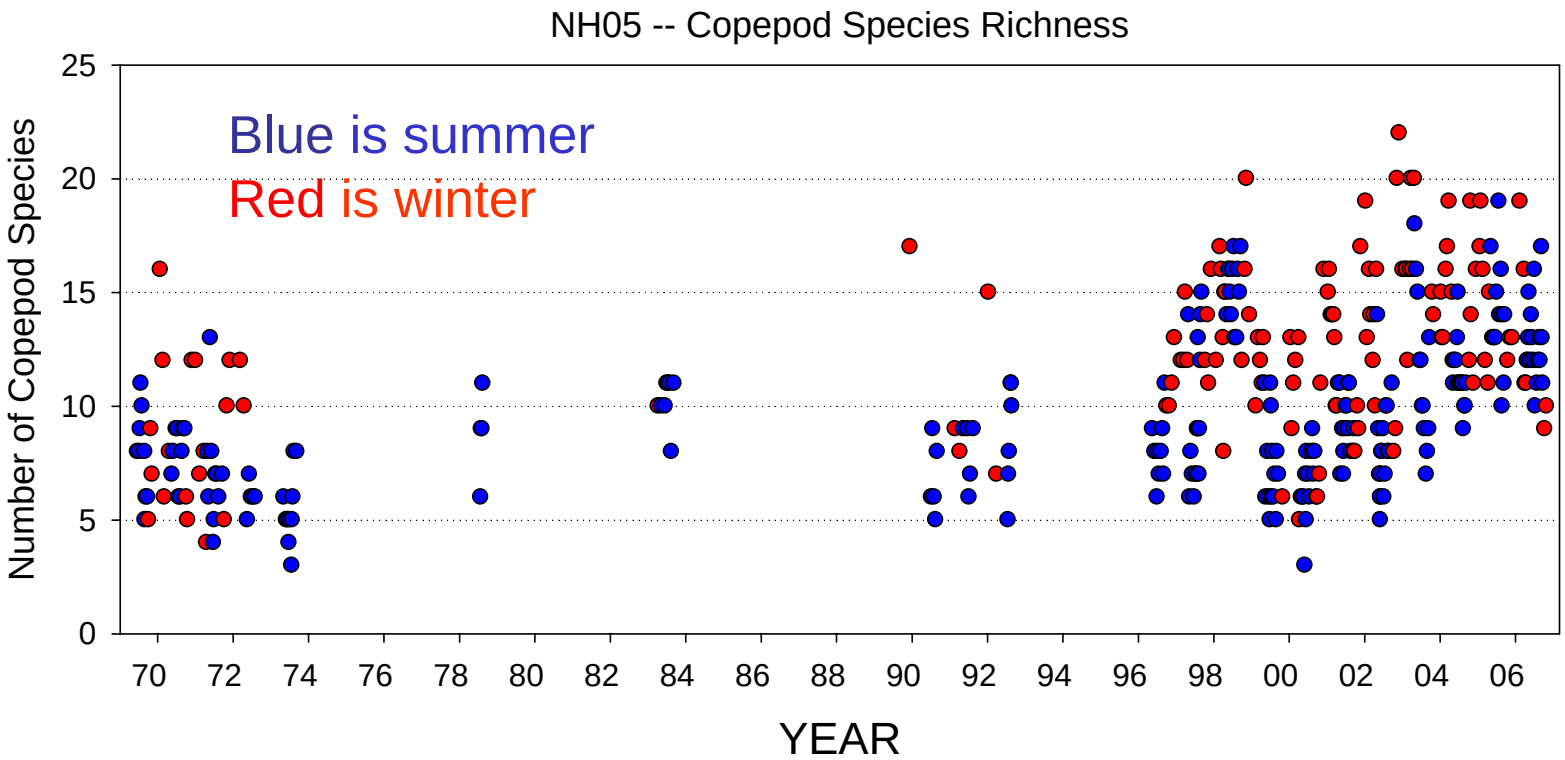
Copepod biodiversity has increased over the past few years



A more diverse copepod community is seen now as compared to 1970s. Thus the "cool phase" of 1999-2002 is different from the cool phase of 1947-1977, perhaps because basin-scale winds are more westerly? This may be first indication that we will find a different copepod community (and different food chain structure) in the FUTURE.

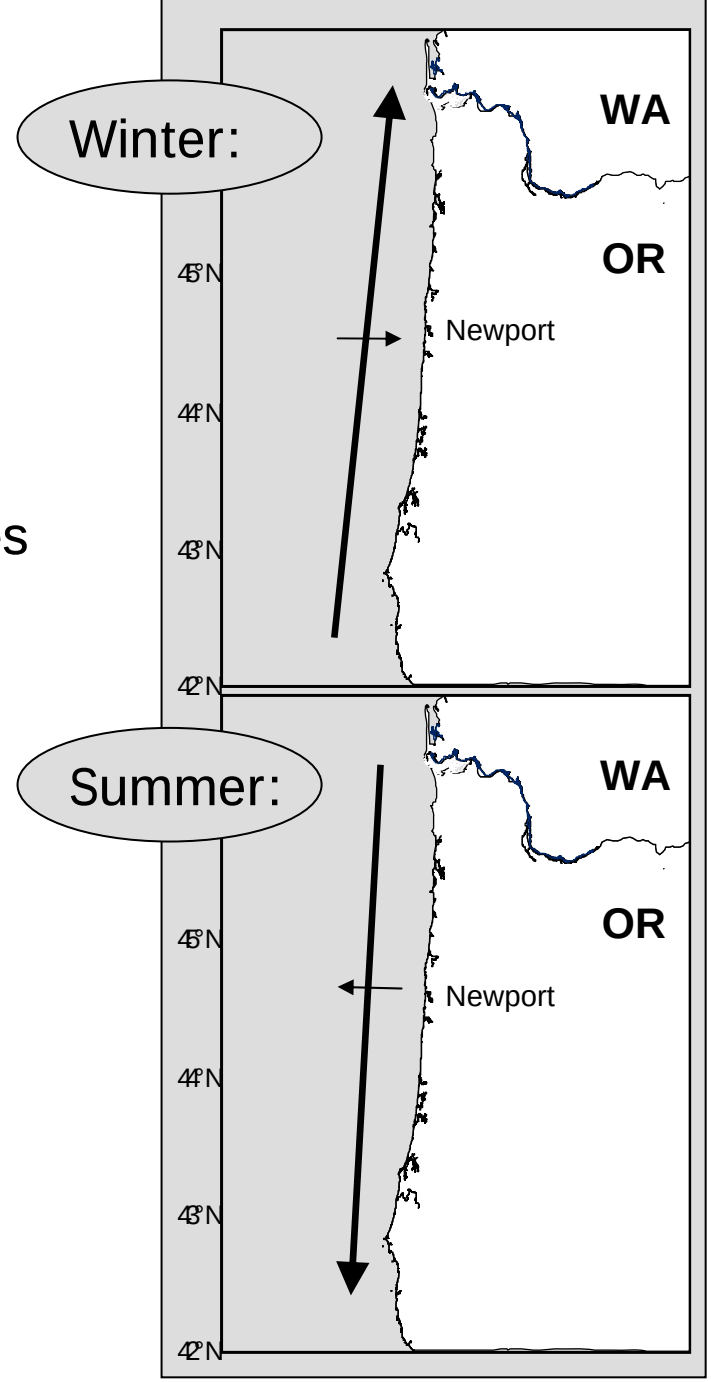
Winds and current structure off coastal Oregon:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Subtropical and southern plankton species transported northward & onshore
  - Many fish spawn at this time

- **Spring Transition in April/May**

- Summer:
  - Strong winds from the North
  - Coastal upwelling
  - Equatorward alongshore transport
  - Boreal/northern species transported southward

- **Fall Transition in October**



12 year time series of zooplankton sampling off Newport shows that monthly anomalies of copepod species richness are correlated with the PDO & MEI